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NONDESTRUCTIVE INSPECTION: IMPROVED CAPABILITIES OF TECHNICIANS

By

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TRAINING SYSTEMS DIVISION
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This report covers two research and development (R&D) efforts relating to non-destructive inspection (NDI) in the Air Force. Recent surveys have found Air Force NDI capability to lack the precision and reliability necessary to ensure the structural integrity of aircraft. In one of these R&D efforts, specifications were developed for a trainer that would allow NDI technicians to learn and practice the ultrasonic NDI technique on the job. Functional specifications were developed first, based on technician-trainer interaction requirements, and then they were converted to engineering specifications for acquisition purposes.

In the other R&D effort reported here, a study was made of relationships between personnel information on NDI technicians and their inspection abilities. The results from extensive eddy current and ultrasonic inspection tests were paired with data on experience, attitudes, and training. No significant relationships were foun tween NDI abilities and selected personnel features.

The specifications for the NDI trainer have potentially wide applicability throughout the military and civilian NDI communities. Results of the survey of personnel information, paired with NDI performance scores, holds interest for the personnel selection system. There is apparently little advantage to prior airframe or metals experience, and neither the volunteer nor the non-volunteer performs inspections with an edge in precision or reliability. The underlying conclusion seems to add weight to the premise that additional practice at the job site is the best approach to improving NDI capability.

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SUMMARY

Recent surveys have concluded that Air Force nondestructive inspection (NDI) capability lacks the precision and reliability necessary to ensure the structural integrity of aircraft. As a result, two urgent needs have been identified: first, a capability for NDI personnel to practice inspection techniques on the job and, second, identification of particular features of good Air Force-trained inspectors. These two needs were the basis of Request for Personnel Research (RPR) 81-08. Objective A of that RPR required detailed functional and engineering specifications for a stand-alone trainer for the ultrasonic NDI technique. Objective B was to examine relationships between personnel information on NDI inspectors and their inspection abilities.

This report covers two research and development (R&D) efforts, one to satisfy Objective A and one for Objective B. An overview of the procedures, a summary of the products, and conclusions concerning applications of results are described for each effort.

Objective A of this project was accomplished in two steps. The first called for a detailed definition of the functional characteristics that the trainer must have in order to provide realistic practice and feedback in the ultrasonic NDI technique. The second step involved converting those functional specifications derived in step #1 into physical specifications adequate for acquisition of a prototype trainer.

Development of functional specifications was based on investigation of the important characteristics of the ultrasonic inspection tasks and definition of the target trainee population. Three sources of information were used: (a) interviews with inspectors at Air Force NDI field laboratories, (b) thorough study of the inspection technical orders (TOs) for several weapon systems, and (c) review of instructional materials and documents used by the Air Training command in the training of ultrasonic inspection techniques. The outcome of the study of inspection tasks and of the technicians who would use the trainer was a series of four instructional modules to be provided through the trainer.

The second step in the Objective A work was to determine what physical characteristics would be needed to accommodate the trainer's functional requirements which were derived in the first step. Fidelity levels and costs were weighed against the potential Air Force need to have one trainer in every base-level NDI laboratory. The decision was made to strive for the minimum acceptable fidelity levels for a simulated test instrument, simulated inspection parts, and simulated calibration standards. Estimated costs of hardware and purchased software are contained in the Appendix to this Special Report.

The specifications for the NDI stand-alone trainer have potentially wide applicability throughout the military and civilian nondestructive testing communities. Both Air Training Command and Air Force Logistics Command have plans for early application of findings from this project.

The intent of the work in support of RPR Objective B was to identify particular features of good NDI specialists and technicians, with the hope it could lead to improved selection, training, and retention in the NDI career field. The features were assessed through questionnaires which were completed by 125 inspectors and 79 of their supervisors. Good inspectors were identified by their scores on a comprehensive job performance test. Test results were paired with the questionnaire data concerning experience, attitudes, and training.

Results of this investigation failed to establish clear-cut relationships between the selected personnel features and inspection skills. However, some of the conclusions which arose from the comparisons may be helpful in programs for selection, training, and retention within the Air Force NDI career field. For example, of interest to the personnel selection system is the finding that prior airframe or metals experience has no impact on inspector performance. In addition, the assumption that volunteers perform inspections with more precision and reliability than non-volunteers is apparently unfounded.

PREFACE

The author expresses deep appreciation for the substantial contributions to this research and development effort by Capt Philip Irish III, Mr. Ira Fiscus, and Capt Tim Fotinos. Capt Irish, Dept of Behavioral Sciences and Leadership at the United States Air Force Academy, performed the personnel survey and a skillful analysis of the data in search of relationships between NDI ability and selected personnel factors. Ira Fiscus, University of Dayton Research Institute, did a most conscientious job of developing and reporting the functional and engineering specifications for the trainer for the ultrasonic NDI technique. Capt Fotinos, Nondestructive Analysis Branch, Directorate of Materiel Management of the San Antonio Air Logistics Center, functioned most efficiently as Air Force Logistics Command monitor of these research and development efforts.

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NONDESTRUCTIVE INSPECTION: IMPROVED CAPABILITIES OF TECHNICIANS

I. BACKGROUND

The work described in this report resulted from an evaluation of the Air Force nondestructive inspection (NDI) capability. This evaluation, sponsored by the Air Force Logistics Command (AFLC), prompted serious allegations concerning the ability of NDI technicians to locate flaws in aircraft structures with the precision and reliability demanded by aircraft design engineers. As a result, the Air Force identified two urgent needs: first, a capability for NDI technicians to practice inspection techniques in field laboratories and, second, identification of particular features of good Air Force-trained NDI inspectors through analysis of relationships between NDI performance and personnel data. These two needs were the basis of Request for Personnel Research (RPR) 81-08. Objective A of that RPR required detailed functional and engineering specifications for a trainer for the ultrasonic NDI technique. The ultrasonic technique was chosen as the objective of this project because it appeared to be the least reliable of the five primary NDI techniques which the Air Force uses. Objective B was to examine relationships between NDI performance and selected personnel information about the inspectors.

This report describes a contract effort and an in-house work unit in support of RPR 81-08; it also includes an overview of the process, a summary of the products, and conclusions concerning applications of the results. More detailed information is contained in Fiscus (1983); Fiscus & Strnat (1983a, 1983b).

II. OBJECTIVE A

The purposes of the trainer to be specified in Objective A were to provide a capability for Air Force 3-level (apprentice) technicians to practice the application of contact-type pulse echo ultrasonic inspection with feedback from the trainer regarding the accuracy of their performance. This capability would allow technicians to practice during duty hours in the laboratory environment as their schedules permitted. Such an arrangement would reduce the demand for instructors on the job and would provide training with uniform instructional content for all inspectors. Perhaps most important, a trainer at the job site would ensure the opportunity for those technicians who perform ultrasonic inspections infrequently to develop and retain the requisite proficiency.

Objective A of this effort was accomplished in two steps (Fiscus, 1983). The first step called for a detailed definition of the functional characteristics that a stand-alone NDI trainer must possess in order to provide realistic practice and feedback in ultrasonic inspection. The second step involved converting those functional specifications derived in step # 1 into physical specifications adequate for use by an acquisition agency in contracting for production of a prototype trainer.

Analysis and design work were based on investigation of the important characteristics of the ultrasonic inspection tasks and definition of the target trainee population. Three sources were used: (a) interviews with inspection technicians at NDI field laboratories, (b) thorough study of the inspection technical orders (TOs) for several weapons systems, and (c) review of instructional materials and documents used in development and conduct of resident training of ultrasonic inspectors at the Technical Training Center at Chanute AFB.

The interviews with inspectors addressed issues such as (a) which NDI tests they perform and the frequency of each, (b) the types of flaws being sought and how frequently they are found, (c) the instruments being used, (d) the weapons systems being inspected, and (e) the characteristics they would like to see in a trainer. Interviewers learned that ultrasonic inspections are performed rather infrequently at many Air Force installations and that flaw finds are also infrequent. Technicians interviewed were not confident in their use of the flaw detector instrument used in ultrasonic inspections.

Study of TOs for a number of weapons systems yielded information concerning the numbers of part shapes inspected and of calibration standards used, the materials involved in inspections, and the types of flaws encountered. Some TOs were found to be so precisely stated and well illustrated that, at least in theory, satisfactory inspections would demand only enough knowledge to follow TO directions.

An examination of resident training materials used by the Air Force to train technicians for ultrasonic inspection indicated that it is reasonable to expect 3-level (apprentice) graduates to perform acceptable inspections at the time of graduation.

The outcome of interviews with inspectors, study of weapons systems TOs, examination of recent occupational survey data (Griffith & Landry, 1979), and review of existing training materials was a definition of the tasks that should be included in the trainer. These tasks were clustered to form instructional modules, and behavioral objectives were written for each one. The description of the characteristics of the technicians who would use the trainer was also an integral part of the determination of the trainer's instructional content. Consequently, Module #1, Prerequisite Knowledge Evaluation Module, was designed to furnish a measure of the depth of the user's knowledge of the principles and procedures in ultrasonic inspection at the time that a user starts to use the instructional modules. It would then be possible to branch from specific areas of the preassessment module to any other module, depending on the user's specific needs.

Interviewers found general consensus among NDI technicians that correct operation of the flaw detector instrument is a problem for new technicians and for those who use the instrument infrequently. (It is common practice for the inspectors in a laboratory to specialize in one technique, so that even where ultrasonic inspections are performed, some technicians do not perform them.) To address this problem, Module #2, Instrument Familiarization Module, was designed to refresh the technicians' knowledge of instrument operation. In like fashion, Module #3, Transducer Manipulation Module, was developed to separate, for both practice and evaluation purposes, the motor activity skills of transducer manipulation from the other activities involved in inspections. Module #4, Practice Exercises Module, is a series of practice inspections in which the user performs simulated inspections and receives immediate feedback from the simulated flaw detector instrument, as well as augmented feedback in each of the inspection steps. The practice exercises, in order to be realistic, require varying amounts of knowledge over and above the ability simply to follow TO directions. These exercises can be used to diagnose deficiencies so that the technician who experiences problems in manipulating the transducer, for example, will be referred to Module #3.

After training requirements for the trainer had been defined and the behavioral objectives written, characteristics of the training environment were described. It was then possible to delineate the trainer and trainee actions which would be necessary for attainment of the module objectives. This led to identification of the instructional features that the trainer must have to assist the user in achieving the objectives and acquiring/practicing the relevant skills.

The second step in Objective A was to determine what physical characteristics the trainer would need to accommodate the functional requirements derived in the first step. Converting the functional statements to physical specifications involved several major decisions. Cost was a practical consideration that was heavily weighted in these decisions. For the trainer to be affordable in every Air Force NDI laboratory, the cost would have to be held to the minimum. However, for the practice and instruction capability to be beneficial, the simulations provided by the trainer must be realistic. Therefore, the issue of fidelity required extensive and detailed analysis. The specification with maximum fidelity would call for a real flaw detector instrument to be used on real parts and a "smart" trainer to critique the technician's procedures, techniques, and decisions. Because such features are not economically feasible, some compromises had to be made. The two major problems in approximating as closely as possible the "smart" NDI trainer are feedback of the transducer's position and orientation from the part to the trainer and analysis of the ultrasonic waveform echoes by the trainer so it can interpret the signal the user is observing. The decision was made to strive for the minimum fidelity levels required for a simulated instrument, simulated parts, and simulated calibration standards. In some issues, such as application of couplant, when two fidelity levels were suggested by the analysis, the minimally acceptable one was specified for the trainer and the other was described and priced as an option. (The Appendix contains estimated costs of hardware and purchased software.)

The complex array of variables that must be monitored and controlled when the technician uses the trainer in Modules #2, #3, and #4 requires the application of an electronic controller. Since the controller is mandatory for those modules, it can then be used for Module #1. It will allow the trainer to present, score, and report results of the pretest electronically by receiving inputs from the user via a keyboard and communicating to the user by means of a graphics terminal.

Perhaps the most vital service for the trainer to provide to the user is augmented feedback, such as whether a flaw was accurately reported. This feedback is essential to learning and is missing in normal job performance of ultrasonic inspections. The feedback should be immediate if it is to be effective. To provide adequate and timely feedback, the trainer will receive notice from the technician of each step completed. The trainer will respond to these completion notices with "correct" or "incorrect."

Life cycle costs for this trainer are difficult to predict because it employs a great deal of new technology that does not yet have established records of reliability or maintainability. However, in order to fulfill Objective A requirements for life cycle costs, experience with similar equipment was used as a baseline, and 15-year costs were estimated.

III. OBJECTIVE B

The intent of the work in support of RPR Objective B was to identify particular features of good NDI technicians, with the hope it would lead to improved selection, training, and retention in the NDI career field. The features were assessed through questionnaires. Good inspectors were identified by their scores on a job performance test that consisted of a set of flatplate hardware instruments, each possessing fastener holes and mounted on an "erector set" framework. Specified holes in each flatplate were laboratory fatigued to cause precise predetermined crack growth. Interchanging the relative positions of the flatplates within the set allowed testing of a large number of technicians without fear of test compromise. In the evaluation each of 205 test participants inspected the "erector set," using both the ultrasonic and eddy current methods.

In addition to these actual performance measures, personnel information was also gathered on 125 of the inspectors and on 79 of their immediate supervisors between October 1981 and May 1982. The inspectors responded to questionnaires within a few days of completing the job sample tests. The questionnaires began with several identification queries such as name, social security number, job title, sex, and DoD employment status (i.e., military or civilian).

Of the respondents,

1. 63% were military (E-1 through E-9) and 37% were civilian.

2. 87% were male and 13% were female.

3. 14% had less than a high school education.

4. 50% had completed high school only.

5. 25% had as much as 2 years of college.

6. 11% had completed more than 2 years of college.

In spite of the apparent range of respondents, there remain the questions of validity and reliability of the data, for if those who did not respond feel differently about USAF NDI than those who did, the reported data would be invalid.

Answers to the questionnaire items were tabulated and response frequencies for each answer were computed. In addition, answers to questionnaires were evaluated in light of the results of the eddy current and ultrasonic job sample tests. Relationships to inspection performance tests were reported as follows:

1. The amount of formal schooling appeared to have no significant relationship to how well the inspector performed.

2. A slight tendency was found for technicians with more than 2 years of college to have fewer false calls ($p = .0004$).

3. Neither eddy current nor ultrasonic test data showed a relationship to amount of NDI training (Air Force or civilian).

4. The 17% of respondents who stated they were certified by the American Society for Nondestructive Testers (A.S.N.T.) performed somewhat better in making finds than did noncertified inspectors on both eddy current and ultrasonic tests.

5. There was no indication of a relationship between performance and whether a technician was a volunteer for the NDI career field.

6. Previous airframe or metals experience before NDI training did not appear to impact ability to perform on either eddy current or ultrasonic tests.

7. Technicians who indicated intention to re-enlist in the Air Force seemed to score more finds and false calls than did those without such intention. (p = .002 to .005)

8. No significant relationship was found between inspector performance and degree of like/dislike for present job or for the NDI career field.

9. No relationship was seen between inspection test performance and self-ratings on those abilities. In addition, although eddy current and ultrasonic skills were shown to be quite independent of each other (R = .211 for find rates and R = .274 for false call rates between the two techniques), self-ratings on the two techniques were substantially correlated (R = .6679)

10. Performance on eddy current and ultrasonic tests was not related to degree of comfort/discomfort technicians felt with equipment used in the inspection tests.

11. The technicians' ratings of local on-the-job training or existing resident training for NDI was not related to performance on inspection tasks.

12. Neither the amount of time spent on NDI tasks nor the time spent on individual NDI techniques in the present job was related to the ability to find flaws.

13. The most frequent suggestion for improving overall NDI capability was to provide for more hands-on practice.

14. Supervisor ratings of technician proficiency correlated no better with inspection test performance than did the technicians' self-ratings in Finding #9.

15. There was large variability in eddy current and ultrasonic inspection performance across the sample -- among technicians and across bases and commands. In general, inspection results were too inconsistent for maintenance managers to have confidence in the NDI capability.

IV. CONCLUSIONS AND RECOMMENDATIONS

Although the functional and engineering specifications developed in this project for the ultrasonic NDI trainer have not been evaluated in a prototype, there are indications that it may contribute substantially to satisfying the Air Force need to improve NDI performance. The infrequent use of the ultrasonic technique by many technicians seems to make it unlikely that the ultrasonic inspection skills of those technicians can be maintained at the necessary levels of precision and reliability merely through performance of their jobs. Rather, maintaining such levels requires that job performance requirements be supplemented with some practice of the ultrasonic technique. Further, the inspectors' uncertainty about use of the flaw detector instrument may be viewed as evidence in favor of using a trainer for instruction and practice.

The survey of personnel information for pairing with eddy current and ultrasonic performance test scores failed to identify clear-cut features which correlate with inspection skills. This may be due to such factors as inadequacy of the sample surveyed or the fact that, overall, the performance test scores were low and thus too homogeneous to allow clear-cut discriminations. However, there were some distinct indications which may be helpful. For example, the stated belief of many inspectors that more opportunity for practice would improve NDI capability appears to lend support to the trainer approach. Likewise, the superior inspections by A.S.N.T.-certified technicians may imply a probability of improving performance through the opportunity to practice with the trainer.

The program of selection of people for the NDI career field may find substance in findings of the personnel survey. Prior airframe or metals experience has no impact on technician performance, and neither the volunteer nor the non-volunteer has an advantage in inspection tests. On the other hand, there is indication that increased academic education may improve chances for better ultrasonic test performance.

There is keen interest within the civilian nondestructive testing community in the efficiency and effectiveness of a stand-alone job site trainer for enhancing the skills of inspectors. The San Antonio Air Logistics Center plans to use the specifications developed by this effort for acquisition of a prototype trainer. In addition, the Air Training Command may test and evaluate a prototype in the NDI resident training environment. The Statement of Work for the prototype production may include only those items specified for the trainer, or the decision may be made to select, instead, some of those items described and priced as options. If the prototype trainer proves to be efficient and effective in the job environment or in a resident training environment, there will undoubtedly be similar efforts to apply the trainer technology to some of the remaining NDI techniques.

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APPENDIX: COST ESTIMATES OF SPECIFIED HARDWARE AND PURCHASED SOFTWARE

Final cost estimates for hardware and purchased software appear in the following table. Cost estimates are based on available hardware that can be interfaced to function in the system being specified. Equivalent equipment may be substituted for any of the components listed. Sources of the costs shown can be identified by the following codes:

C = Catalog price
Q = verbal or written quotation
EE = engineering estimates

Estimated Hardware and Purchased Software Costs

Unit	Manufacturer	Model No.		Unit Cost
Main CPU 68000 CPU board with 4 channel DMA controller, 128 kbytes RAM, 64 kbytes ROIM, 4 serial ports, UNIX, CP/M, 2-iSBX connectors.	Heurikon Corporation 3001 Latham Drive Madison, WI 53713 (800) 356-9602	HK-68A	Q	$3735
Multibus 14 slot multibus enclosure with power supply and cooling fans.	Heurikon Corporation 3001 Latham Drive Madison, WI 53713 (800) 356-9602	MLZ814	Q	2645
Memory 128 kbytes, RAM memory board for multibus	Chrislin Industries, Inc. Computer Products Div. 31352 Via Colinas, #101 Westlake, CA 91362 (213) 991-2254	CI-8086	Q	645
Disk Storage 40 Mbyte Winchester disk and 1.2 Mbyte floppy disk, with controllers	Chrislin Industries, Inc. Computer Products Div. 31352 Via Colinas, #101 Westlake, CA 91362 (213) 991-2254	MLZ-FW	Q	7045
Keypad Membrane Keypad	RCA 29525 Chagrin Blvd Pepper Pike, OH 44122 (216) 831-0030		EE	500
Graphics Terminal 768 X 585 Resolution Monochrome	Modgraph Inc. 1393 Main Street Waltham, MA 02154 (617) 890-5764	G-100	Q	2995
Array Processor	Sky Computer Inc. Lowell, MA 01853	Skymnk	C	$7050
Peripheral Processor 1&2 Intelligent analog peripheral with 16 kbytes on-board dual-port RAM, 16 kbytes on-board EPROM, 16 channels of 12-bit A/D, 1 serial interface, 2 timers, DMA	Data Translation 100 Locke Drive Marlboro, MA 01752 (617) 481-3700	DT3752	Q	$3750 (2 required @ $1875)
Multifunction expansion system with 4 12-bit D/A converters, 48 parallel I/O lines, 8 kbytes on-board EPROM, Floating point processor, 5 timers with time of day clock, 1 serial interface		DT3760	Q	$3150 (2 required @ $1575)

Unit	Manufacturer	Model No.		Unit Cost
Digitizing (Graphics) Tablet 12" X 12" Active Surface	California Computer Products Inc. (Calcomp) Anaheim, CA 92801	3120	Q	1149
Standard Controller	Calcomp	8000	Q	2850
57 Line Parallel Interface	Calcomp	8044	Q	655
Two Pen Assemblies w/o ink	Calcomp	8093	Q	324
Oscilloscope Screen Includes Power Supply, TTL blanking, input connector	Tektronix, Inc. P.O. Box 1700 Beaverton, OR 97075 (503) 627-7111	620	Q	1400
				$20,328
Simulated Flaw Detector Instrument Components Power Supply, Knobs, Switches, Potentiometers, Cabinet, Cables, Connectors and Misc.	Various	Various	EE	$ 575
Practice Exercise Overlays Printed Mylar Sheets, estimate 40 each	Various		EE	600/40 pieces
Trainee Work Station Table top with storage compartments	Various		EE	500
Purchased Software Operating System	Heurikon Corporation 3001 Latham Drive Madison, WI 53713 (800) 356-9602	UNIX	Q	1500
System Diagnostics	Heurikon	HBUG	Q	300
Principal Programming Language	Heurikon	FORTRAN or PASCAL	Q	600
				$41,968*
Optional Couplant Simulation System				
Couplant Simulation Ultrasonic thickness detector	NDT International, Inc. West Chester, PA 19380	NDT Over-roll Monitor	C,Q	2695
A/D Converter	Data Translation 100 Locke Drive Marlboro, MA 01752 (617) 481-3700	DT-1742-D1	C,Q	500

*Total includes array processor.